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The Dependence of High-Precipitation Supercells on Preexisting Airmass Boundaries: A Targeted Modeling Study

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1. Introduction

Severe and hazardous weather is often observed with and correlated to the presence of supercell thunderstorms. In fact, it is generally assumed that supercells are responsible for a significant amount of the severe weather and damage which results from thunderstorms (Moller et al. 1994; Doswell 2001). Three morphologies of supercells are recognized (Moller et al. 1994): low-precipitation, classic, and high-precipitation. Classic supercells are best known for their propensity toward tornado production and have therefore dominated the literature on supercells; however, it is postulated that high-precipitation (HP) supercells are the most commonly observed supercell morphology in the United States (Moller et al. 1994). In addition to their abundance, HP supercells pose the threat of flash flooding and large amounts of significantly severe (diameter $\geq$ 5 cm) hail (Nelson 1987), which are both significant hazards to life and property.

It is not generally known how and where HP supercells tend to form, due to their sparse appearance in literature. Moller et al. (1990) hypothesizes that HP supercells “almost always” form and travel along preexisting boundaries; however, an investigation of this hypothesis has never been made. Although it is not hypothesized explicitly in literature, HP morphology along boundaries could be due to the interaction of a non-HP storm with surrounding convection, since convergence along a boundary makes it a preferred location for convective development. Such a merger would allow precipitation to fall near the updraft and into the midlevel mesocyclone, which may work to wrap precipitation around to the rear of the updraft, thus defining it as HP. Brooks et al. (1994) and Rasmussen and Straka (1998) theorize that weak mid-to-upper level storm relative winds promote precipitation falling near and to the rear of the updraft instead of being exhausted away from the updraft by stronger mid and upper level winds; however, this study suggests that more than one mechanism can produce the HP morphology.

The hypothesis that preexisting boundaries affect supercell morphology is tested by simulating convection in an environment represented by an actual HP event. The case that is used in this study is that of an HP supercell which formed along an outflow boundary in the panhandle of Texas on 25 May 1999 (Dostalek 2004). It is important to note that these idealized simulations are *based* on this case but do not seek to

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replicate the event. Environmental soundings from each airmass, interpolated from the North American Regional Reanalysis (NARR; Mesinger et al. 2006) dataset, serve as the initial conditions for the domain, while the boundary itself has been prescribed to best resemble the available surface and wind profiler data. Three simulations are run for analysis in this study: one simulation with the boundary, one simulation of the warm airmass without a boundary, and one simulation of the cool airmass without the boundary. The two homogeneous simulations are done to judge whether or not the HP morphology is sensitive to increased moisture and shear on the cool side of the boundary or the increased CAPE on the warm side.

2. Data and Methodology

The model used in this study is the Illinois Collaborative Multiscale Model for Atmospheric Simulations (ICOMMAS; Houston 2004), a non-hydrostatic, finite difference model. ICOMMAS is similar to its predecessor, COMMAS (Wicker and Wilhelmson 1995), but was designed specifically to study the relationship between convective initiation and airmass boundaries. The microphysics scheme used in these simulations is a three-phase ice parameterization (Gilmore et al. 2004) which has been previously used with ICOMMAS (Houston and Niyogi 2007).

In simulations without a boundary, the typical thermal bubble approach is used to initiate convection. The thermal used has horizontal radii of 5000 m, a vertical radius of 1000 m, and is centered at 1000 m AGL. A 1.5 K perturbation is present in the center of the bubble, and decreases to zero on the edges.

In order to capture the supercellular nature of a convective thunderstorm while limiting simulations to reasonable computational time and resources, a grid spacing of 500 m was used in the horizontal, while a vertical grid spacing which stretched from 50 m in the boundary layer to 500 m in the upper troposphere was used.

To study the effect of a preexisting boundary on HP supercells, it was necessary to quantify the HP character of the storm both in radar data and model output. This was done using reflectivity data for the case study and surface precipitation as a proxy for reflectivity data in the model results, as well as a method proposed by Beatty et al. (2004) (hereafter, B04). In brief summary, this method compares the location of the reflectivity centroid in a supercell to the location of the low-level updraft, and determines whether the centroid is behind or ahead of the updraft, relative to storm motion.

A few modifications were made to B04's method for use in this study, most of which were made for greater ease of computation. Instead of using rainfall rate determined from a Z-R relationship for locating the centroid on radar, raw reflectivity values were used. Since all data were treated the same, this produced the same result as would have been obtained using rainfall rate. In addition, weighting of the reflectivity values by its position of a 2-D grid was done using azimuth angle and radial position instead of position on a Cartesian grid. These coordinates were also used for determining the location of the updraft, which gave an end result that would not significantly differ from an exact replication of B04's approach.

After determining the position of the centroid and the updraft, B04's approach would define the storm as HP or non-HP by whether or not the centroid was behind the updraft relative to storm motion. This is where the method used herein deviates from the method used by B04. The HP character of a storm is defined by the proximity of heavy precipitation to the mesocyclone and not its radial position relative to the updraft. Thus, a two-stage method is used to determine the degree to which that storm can be defined as HP. First, the percentage of the updraft which is surrounded by reflectivity of a certain threshold within a specified distance is determined. Next, the distance of the centroid to the updraft was considered as a measure of how much heavy precipitation is falling near the updraft. Regardless of its radial position, a centroid which is closer to the updraft is more HP than a centroid further away.

For analysis of the case study, radar data were obtained from the National Climatic Data Center (NCDC) and were converted to netCDF format by the Warning Decision Support System – Integrated Information program (WDSS-II; Lakshmanan et al. 2007). These data were then read into an algorithm to determine the location of the centroid and updraft, as well as the percentage of the updraft surrounded by convection. While B04's method of determining HP character gives a very cut-and-dry, HP or non-HP answer, the method described above was used to determine its "HP-ness", or to what degree the storm could be defined as HP. Since no study has before attempted to quantify HP character on radar in this manner, it is not yet known what thresholds will be used to quantify HP-ness. The opinions of the scientific community will be compiled to aid in creating these thresholds.

3. Results

In both homogeneous simulations, a storm formed but did not become a supercell. However, the simulated storms were far from identical – a few important characteristics separated the warm side and cool side storms from one another. In the warm side simulation, the highest reflectivity recorded at the surface is just over 45 dBZ, while in the cool side simulation, the surface reflectivity exceeds 54 dBZ. The cool side storm also distributes precipitation over a larger surface area than the warm side storm. While the cool side storm cannot be defined as HP without supercell characteristics, it is important to note that considerable precipitation (surface reflectivity values in excess of 40 dBZ) falls near and in the main updraft. The main updraft in the storm simulated in the warm side is more isolated from precipitation.

A supercell has not yet been produced in a boundary simulation. However, work still has to be done in order to create a boundary that closely resembles the outflow boundary present on 25 May 1999. Once a more realistic boundary is produced, it is likely that a supercell will form in the boundary simulation.

4. Conclusions and Future Work

Preliminary results are encouraging in that neither storm became a supercell, suggesting an influence from the boundary, and also in that the cool side storm was much more similar to an HP supercell, suggesting an influence from the environment on the cool side of the boundary. Once a supercell is produced along the boundary, detailed analyses will then be performed to determine the specific influence of the preexisting airmass boundary on supercell formation and morphology.

Once an HP supercell is produced, timing of storm mergers and their correlation to surface precipitation rates and location will be examined. In addition, precipitation trajectories will be examined to determine the source of surface precipitation within the HP supercell. To test the influence of the cooler and more moist airmass on the morphology, tracers will be placed in the cool airmass to determine the original location of air moving into the updraft.

The results could have potentially far reaching effects into both the scientific and operational fields. Within the National Weather Service, staffing and preparation can be quite different based on what type of severe weather is expected. Although preexisting boundaries are already recognized as a location for severe convective development, knowledge of a preference for HP morphology along a boundary would allow forecasters to prepare more specifically for an HP supercell event. In the scientific community, a study such as this would encourage both climatologies of HP supercell formation and more ambitious modeling studies to determine the sensitivity of HP formation to environmental conditions associated with the boundary.

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